JUL 15 1965

ATSS-10

National Aeronautics and Space Adminsitration
Goddard Space Flight Center
Contract No. NAS-5-3760

ST — IM — 10355

MEASUREMENTS OF THE INITIAL RADII OF IONIZED METEOR TRAILS FROM PARALLEL OBSERVATIONS OF RADIOMETEORS IN TWO WAVELENGTHS

by

I. V. BAYRACHENKO

[USSR]

CC

13 JULY 1965

ST - IM - 10355

MEASUREMENTS OF THE INITIAL RADII OF IONIZED METEOR TRAILS FROM PARALLEL OBSERVATIONS OF RADIOMETEORS IN TWO WAVELENGTHS

Geomagnetizm i Aeronomiya,
Tom 5, No. 3, 460 - 464,
Izdatel'stvo "NAUKA", 1965

by I. V. Bayrachenko

SUMMARY

This paper defines the initial radii of ionized meteor trails from the analysis of general amplitude-temporal characteristics of the radioechoes obtained in the frequencies $f_1 = 31.26$ mc, $f_2 = 46.2$ mc. For an average height of 96.8 km and a mean velocity of 41 km/sec, the mean value of the initial radius $r_o = 1$ m. The dependences of the initial radius on height and meteor velocity are obtained.

*

* *

Numerous radar observations of meteors show, first of all, that for a wavelength $\lambda \leq 6$ m the number of radioechoes decreases sharply, and secondly, that with the increase in velocity of weak meteors (+6 st.magn.) the observed heights are systematically lower than the forecast [1]. These experimental facts can be explained only by the presence of great initial radii of ionizing meteor trails.

Kaiser [2] assumed that the initial radius of a trail will be of the order of the length of the free path of air molecules at the height of meteor appearance, that is of several centimeters. However, the vaporizing atoms have a high kinetic energy on account of meteor body velocity, and consequently, the ionization rate is high at the

* IZMERENIYA NACHAL'NYKH RADIUSOV IONIZIROVANNYKH METEORNYKH SLEDOV IZ PARALLEL'NYKH NABLYUDENIY RADIOMETEOROV NA DVUKH DLINAKH VOLN.

outset, so that we must have, almost instantaneously, a spatially distributed ionization instead of a point source [3]. Manning [4] investigated this question from the standpoint of the kinetic theory of gases and he has shown, that on account of high initial velocity of meteoric atoms, the initial radius, from which the normal diffusion takes place, is reached very rapidly; at the same time, the value of the initial radius will be of the order of three length of atmosphere molecules' free path λ_a at the corresponding height. Since radiometeors are observed in a narrow altitude interval, 90 – 100 km, where λ_a varies from 2 to 10 cm [5], the initial radius of ionizied meteor trails varies, according to [4], from 6 to 30 cm. Similar results were arrived at also by Loshchilov [6], who investigated that question with the aid of atomic collisions' theory. The influence of the initial radius on the amplitude of the radioecho from a nonsaturated trail manifests itself when the radius is comparable with the quantity $\lambda/2\pi$. Thus, according to [4], the initial radii may be disregarded at $\lambda \geqslant 2$ m, which is in contradiction with experimental data. B.L.Kashcheyev and V.N.Lebedinets [7] computed the initial radius of the trail more strictly, determining the length of the free path of ions and atmosphere molecules respectively by the diffusion cross section for ions and atmosphere molecules. They found, that accounting of the dependence of the length of the free path of ions on velocity leads to the increase of the initial radius by comparison with the Manning calculations [4].

Greenhow and Hall [8] materialized an experimental method for the determination of the initial radii of meteor trails, conducting parallel observations of the same meteors providing nonsaturated trails at wavelengths of 17 and 8 meters. According to their data, the initial radius varies from 1 to 3 m between the heights of 90 and 115 km, this value being independent from meteor velocity.

B.L.Kashcheyev and V.N. Lebedinets [7] also conducted experimental measurements of the initial radii of trails in the wavelengths of 8 and 4 m. For an average height of 95 km they obtained $r_0 = 80$ cm, which agrees satisfactorily with the theoretical forecasts. However, the measured dependence of r_0 on the geocentric velocity of the meteor was found to be somewhat less than the theoretical.

Therefore, in spite of the fact that the radar method of determination of the initial radii is the most reliable, only two experiments have been carried out to-date. When determining the order of magnitude, both experiments gave close results. However, the obtained dependence of the initial radius on velocity is quite different. Thus, additional experiments are necessary, by way of parallel observations in two wavelengths, and preferably in another frequency band.

METHOD OF THE EXPERIMENT.-

In case of nonsaturated meteor trails, the power of the reflected signal at receiving device input is [7]: *

$$P_{\text{пр}} = \frac{P_{\text{п}} G^2 \lambda^3 \alpha^2}{32\pi^2 R^3} \left(\frac{e^2}{mc^2}\right)^2 e^{-2(2\pi r_0/\lambda)^2} |I|^2 \quad \left(I = \frac{1}{\sqrt{2}} \int_{-\infty}^{x_0} e^{j\pi/2}\, e^{-\Delta(x_0 - x)}\, dx\right), \qquad (1)$$

where I is the Fresnel integral with a weight factor

$$\Delta = \frac{8\pi^2 D \sqrt{R}}{V \lambda^{3/2}}, \quad x = \frac{2s}{\sqrt{R\lambda}}, \quad x_0 = \frac{2s_0}{\sqrt{R\lambda}}. \qquad (2)$$

Here P_{π} is the power of the transmitter in the impulse; G is the antenna directional action factor; λ is the wavelength; α is the linear electron density in the trail; R is the slant range; e and m are respectively the charge and the mass of the electron; c is the wind velocity; r_0 is the initial radius of the trail; D is the diffusion coefficient; V is the meteor velocity; s is the distance along the trail's axis from the base of a perpendicular to the trail from the site of the radar station, to the given point of the trail in the direction of motion of the meteor; s_0 is the coordinate of the position of trail's head.

An approximate expression for $|I|_{max}$ is given in [9].

$$|I|_{\max} \approx \frac{1 - e^{-\sqrt{2}\Delta}}{\sqrt{2}\Delta}. \qquad (3)$$

* $P_{\pi p}$ stands for $P_{rec,}$ and P_{π} — for P_{power}

From (1) and (2) the maximum power of the reflected signal is

$$P_{\text{np. max}} = \frac{P_n G^2 \lambda^3 \alpha^2}{32\pi^2 R^3} \left(\frac{e^2}{mc^2}\right)^2 \exp\left[-2\left(\frac{2\pi r_0}{\lambda}\right)^2\right]\left(\frac{1-e^{-\sqrt{2}\Delta}}{\sqrt{2}\,\Delta}\right). \quad (4)$$

According to (4), the ratio of maximum amplitudes of the radio-echo in two wavelengths is

$$\frac{u_1}{u_2} = \left(\frac{P_{1n} G_1^2 \lambda_1^3}{P_{2n} G_2^2 \lambda_2^3}\right)^{1/2} \frac{I(\Delta_1)}{I(\Delta_2)} \exp\left[4\pi^2 r_0^2\left(\frac{1}{\lambda_2^2} - \frac{1}{\lambda_1^2}\right)\right], \quad (5)$$

and hence the initial radius of the trail is

$$r_0 = \frac{1}{2\pi}\left(\frac{1}{\lambda_2^2} - \frac{1}{\lambda_1^2}\right)^{-1/2} \left[\frac{1}{2}\ln\frac{P_{1n}}{P_{2n}} + \ln\frac{u_1}{u_2} + \frac{3}{2}\ln\frac{\lambda_2}{\lambda_1} + \right.$$
$$\left. + \ln\frac{G_1}{G_2} + \ln I(\Delta_2) - \ln I(\Delta_1)\right]^{1/2}. \quad (6)$$

As follows from (6), knowing the apparatus' parameters, the amplitudes of radioechoes in two wavelengths, the slant range and the velocity of the meteor, one may determine the initial radius of the ionized meteor trail.

A special apparatus was designed to that effect, which permits to obtain amplitude-temporal characteristics from the same meteor trail in two wavelengths.

The parameters of our complementary radar installations are : carrying frecuencies: $f_1 = 31.26$ mc ($\lambda_1 = 9.59$), $f_2 = 46.2$ mc ($\lambda_2 = 6.49$), the frequency of pulse repetition is 500 sendings per second, each fifth one being doubled; duration of emitted pulses is 10 sec, with power in pulses being regulated within the range 20 ÷ 40 kw, the sensitivities of the receiver at double excess of signal over noises are 3 microvolt. Separate antennas of the wave type , with 4 elements and situated at 0.5 above an even surface of 60 x 60 m dimensions and oriented westward. The indicator device includes two double-beam tubes, in which two beams are utilized for the determination of slant ranges, and the remaining two, (of slow scanning) — for the determination of amplitude-temporal characteristics. The duration of slow scannings is 0.11 sec. Owing to the selection of such duration, there is a possibility of measuring the velocities of meteors. The information, obtained in the form of amplitude-temporal characteristics of radiowaves, is automatically photographed from the screens of the indicator device.

As to the method of simultaneous observations of radiometeors in two wavelengths, it consists in the following. The synchronizing device works out narrow pulses with a repetition frequency of 500 pulse/sec for the synchronization of the operation of transmitters. Pulses of 100 pulse/sec. frequency serve to trigger rapid scannings of the indicator device, by which the slant range to the meteor trail is determined. The duration

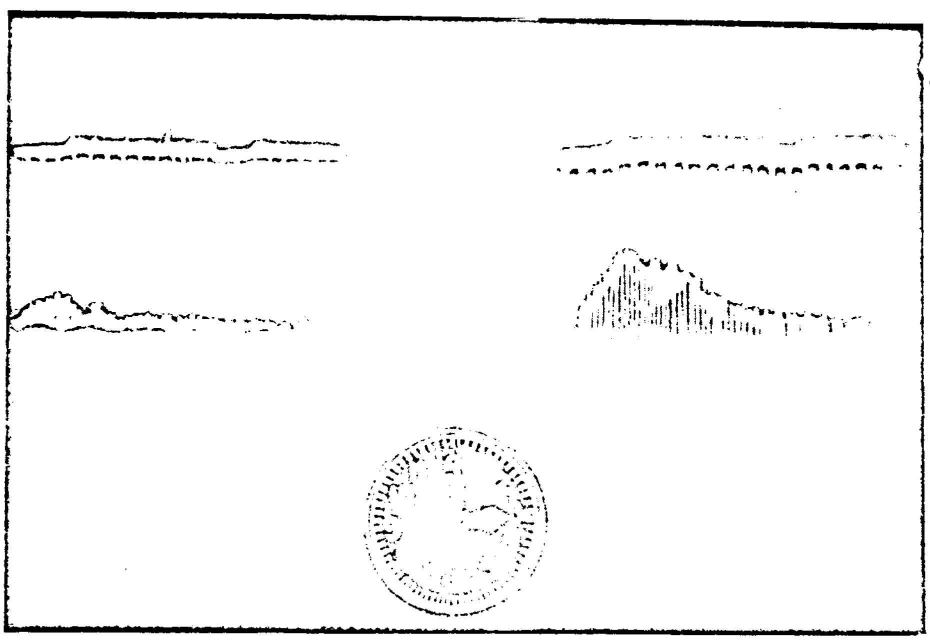

Fig. 1

of the rapid scannings allows to determine unambiguously the range over a distance of 500 km. The unambiguous determination of the range at high repetition frequency of pulses is possible owing to the coding of the emitted pulses (every fifth pulse is doubled). The broad pulses of negative polarity with the frequency of 500 pulse/sec are fed to receiving devices to quench the sounding pulses during transmitter operation.

From receiver output the signals are fed to the noise suppression unit and to amplifiers of the indicator channels. The noise suppressor operates on the principle of selection by duration. In the presence of a useful signal a standard signal appears in any one of the receivers at the output of the noise suppression unit, triggering slow scans of the indicator device.

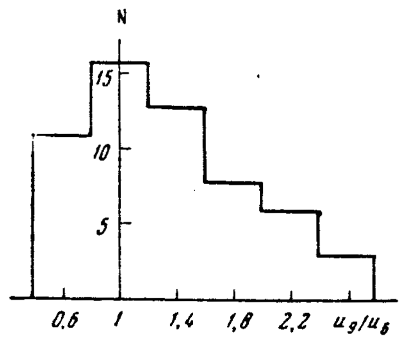

Fig. 2

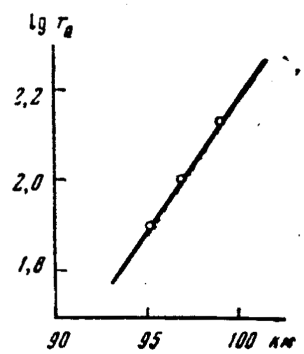

Fig. 3

EXPERIMENTAL RESULTS.

The observation was conducted in October-December 1963, for a total duration of 14 hours. 1660 radioechoes, valid for processing, were sorted on the 9-meter istallation and 930 — on the 6-meter one. As a rule, a radioecho appearing on the 9-meter installation, appears also on the 6-meter one. That is why 930 echoes were common. From the total number of the registered radioechoes sharply expressed, diffraction phenomena were obtained in the process of trail formation in 300 meteors on 9 m and 170 — on 6 m.

For the determination of the value of the initial radius of the trail from the total amplitude-temporal patterns obtained in the two wavelengths, 50 radioechoes were sorted from nonsaturated meteor trails. The external shape of the amplitude-temporal characteristic and the value of the diffusion coefficient served as the criterion for selection. The diffusion coefficient was determined by the exponential drop of the amplitude, as well as by the amplitude ratio at time of the first and second maxima of the diffraction pattern. An example of such a radioecho is presented in Fig. 1.

From the distribution of amplitudes of radioechoes from steady meteor trails (Fig. 2) it is established, that the sensitivity of the 9-meter installation differs from the 6-meter one by a factor of 1.3. This sensitivity factor was taken into account when determining the amplitudes and that is why the equation (6) for our case is simplified as follows :

$$r_0 = 1{,}4\left[\ln\frac{u_1}{u_2} + \ln I(\Delta_2) - \ln I(\Delta_1)\right]^{1/2}. \qquad (7)$$

The height of the reflecting point on the trail was determined by the value of the ambipolar diffusion coefficient [10]

$$h = \frac{\lg D + 5{,}663}{0{,}0679}\cdot 10^3 \ (м). \qquad (8)$$

The mean value of velocity for 50 meteors is 41 km/sec. The mean value of the coefficient of ambipolar diffusion $D = 8.2\ m^2/sec$, which corresponds to $h = 96.8$ km. The mean value of the initial radius $r_o \approx 1$ m.

Plotted in Fig. 3 is the dependence of the initial radius of the meteor trail on height according to measurements at three points : Jodrell Bank [8], Khar'kov [7], and Kiyev. The mean values of the initial radii were obtained at Khar'kov for the mean velocity of 32 km/sec, in Kiyev — 41 km/sec and at Jodrell Bank, apparently for ~ 60 km/sec. As follows from Fig. 3, the experimental points fit sufficiently well the line, approximated by the equation

$$r_0 \sim \rho_0^{-0,82}, \qquad (9)$$

which differs from the expression brought out in [8] ($r_o \sim \rho^{-0.35}$, where ρ is the atmosphere density).

It is necessary to take into account that the variation of the initial radius with the change of height takes place not only as a consequence of the variation of the length of the free path of air particles, but also on account of variation of the initial energy of vaporizing meteoric atoms, for the mean height of a radioecho is a function of meteor velocity.

In order to verify the dependence of the initial radius on velocity by the data of our observations, 34 values were assembled, for which the mean height $h = 96.8 \pm 2.2$ km. They were processed by the method of least squares. The dependence of r_o on V was represented in the form $r_o = aV^b$.

All measurements were equally accurate. When passing to normal equations, it was taken into account that the method of least squares is inapplicable in its pure form in the presence of coordinates' transformation (we passed from r and V to $k = \log r$ and $\xi = \log V$), since the function, satisfying the condition of the minimum of the sums of "misfit" squares in the coordinates (η, ξ) will not satisfy such a condition after transition of basic coordinates. (See [11]). The obtained dependence $r_o = F(V)$ is plotted in Fig. 4; it is approximated by the equation

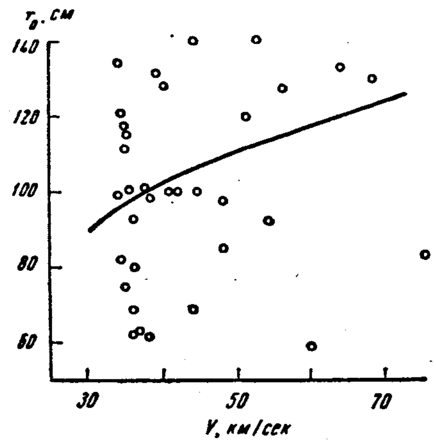

Fig. 4

$$r_0 \sim V^{0,33}. \qquad (10)$$

As follows from [10], there exists a dependence of the initial radius of the trail on meteor velocity, which corroborates the experimental data of the work [7] and diverges from those of work [8]. Note, however, that the dependence obtained by us is notably weaker than was expected according to [7].

The author acknowledges the help afforded by B. I. Mel'nikov in the processing of observations.

**** THE END ****

Contract No. NAS-5-3760
Consultants and Designers, Inc.
Arlington, Virginia

Translated by ANDRE L. BRICHANT
on 12 — 13 July, 1965

REFERENCES

[1].- J.S.GREENHOW, J.E. HALL.- Monthly Notices Roy.Astr.Soc, 121, 174, 1960.

[2].- T.R.KAISER.- Adv.Phys., 2, 495, 1953.

[3].- E.J. OPIK.- Irish Astronom.J., 3, No. 6, 165, 1955.

[4].- L.A.MANNING.- J. Geophys. Res. 63, No. 1, 181, 1958.

[5].- Rocket Panel. Phys. Rev. 88, 1027, 1952.

[6].- Yu. A. LOSHCHILOV.- Tr.Gorogskoy Astronom.Obs.Kazan'Univ. 33, 70, 1961.

[7].- B.L.KASHCHEYEV, V.N.LEBEDINETS.- Sb."Radiolokatsionnyye issledov. meteornykh yavleniy"., No. 7, Izd.A.N SSSR, 1961.

[8].- J.S.GREENHOW, J.E.HALL.- Monthly Not.Roy.Astron.Soc. 121, 183, 1960.

[9].- F.I.PEREGUDOV.- Astronom. Zh. 35, 888, 1958.

[10].- J.S.GREENHOW, E.L.NEUFELD.- J.Atm.Terr.Phys., 6, 2-3, 133, 1955.

[11].- P.V.MELENT'YEV.- Priblizhennyye vychisleniya (Approximate Calcul.) FIZMATGIZ, 1962.

DISTRIBUTION

GODDARD SPACE F.C.

600	TOWNSEND	
	LAGOW	
	STROUD	
610	MEREDITH	
	SEDDON	
611	McDONALD	
	ABRAHAM	
	BOLDT	
612	HEPPNER	
	NESS	
613	KUPPERIAN	
	ALEXANDER	
	McCRACKEN	
	SECRETAN	
	BERG	
614	LINDSAY	
	WHITE	
615	BOURDEAU, BAUER	
	STONE	
	JACKSON	
640	HESS	[3]
	O'KEEFE	
651	SPENCER	
	NEWTON	
252	LIBRARY	[3]
256	FREAS	
660	GI for SS	[5]

NASA HQS

SS	NEWELL, CLARK	
SG	NAUGLE	
	SCHARDT	
	ROMAN	
	SMITH	
	DUBIN	
SL	LIDDEL	
	BRUNK	
	GAUGLER	
	FELLOWS	
	HIPSHER	
	HOROWITZ	
SM	FOSTER	
	ALLENBY	
	GILL	
	BADGLEY	
RR	KURZWEG	
RTR	NEILL	
ATSS	SCHWIND	[4]
	ROBBINS	
WX	SWEET	

OTHER CENTERS

AMES R.C.

SONETT [5]
LIBRARY [3]

LANGLEY

160	ADAMSON	
213	KATZOFF	
	WINEMAN	
231	O'SULLIVAN	
185	WEATHERWAX	[3]

UCLA

COLEMAN

UC BERKELEY

WILCOX

U. MICHIGAN

F. T. HADDOCK